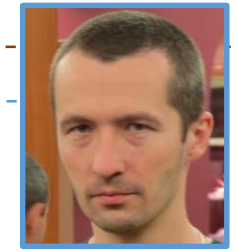
Optička svojstva heterostruktura dihalkogenida prijelaznih metala OhTMD

Projektni tim	Marko Kralj, *voditelj*	*sinteza, upravljanje projektom*
	Nataša Vujičić *suradnik*	*razvoj optičkog setupa*
	Iva Šrut Rakić *suradnik*	*strukturne karakterizacije*
	Borna Pielić *suradnik*	*karakterizacija i optički odziv*
	Davor Čapeta[@PMF] *suradnik*	*sinteza heterostruktura*
	+ Postdoc *suradnik*	*kontaktirani uređaji*
	+ PhD student *suradnik*	*optički odziv uključujući pump-probe*

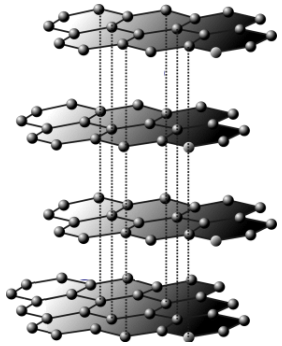



Sadržaj

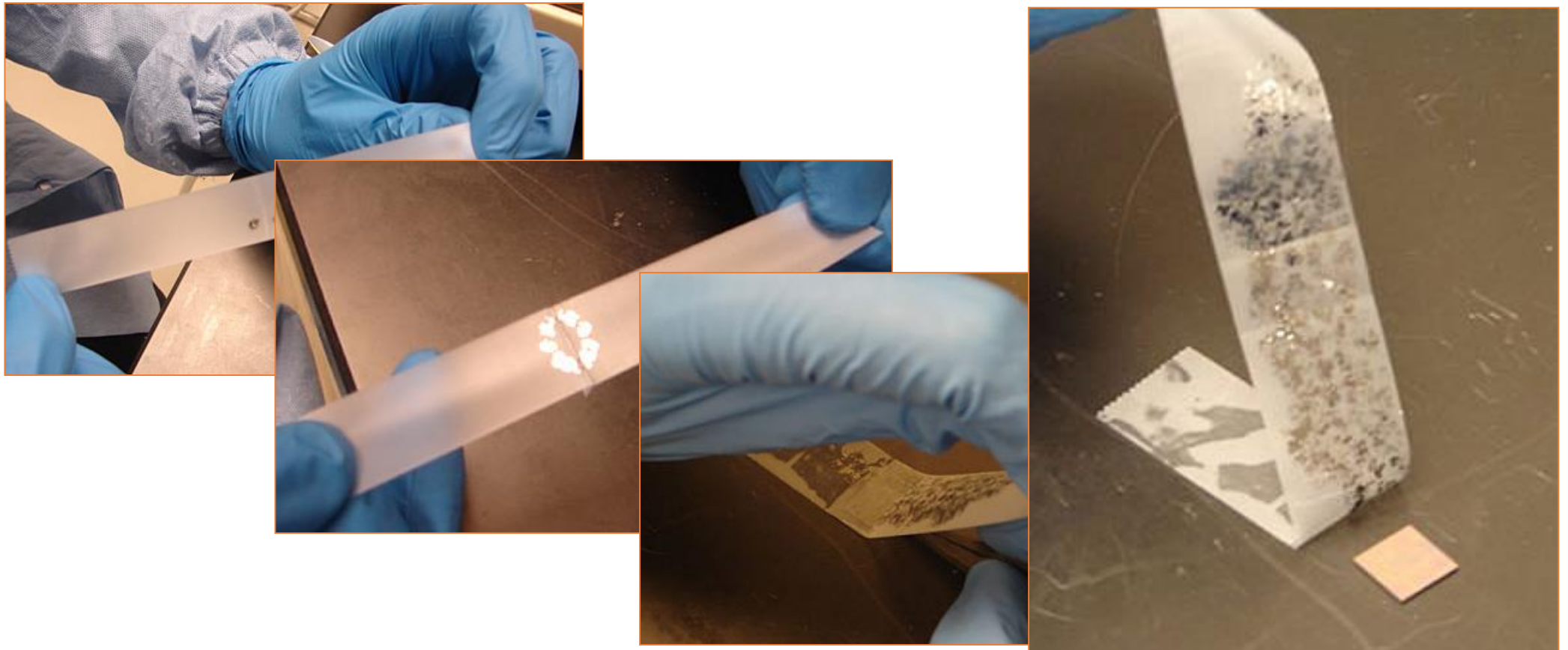
- Uvod u tematiku: 2D materijali i potencijalne primjene
- Optički odziv
- Heterostrukture kao lego kockice

- Glavni ciljevi OhTMD projekta
- Razvoj sinteze i dobivanje heterostruktura
- Karakterizacija optičkog odziva
- Opis budžeta

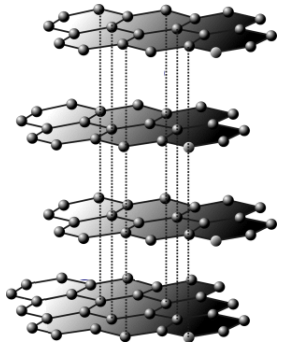
Revolucija dvodimenzionalnih materijala

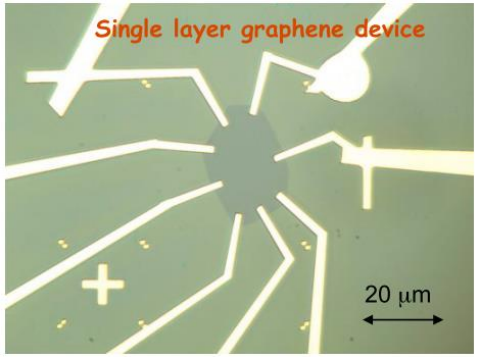


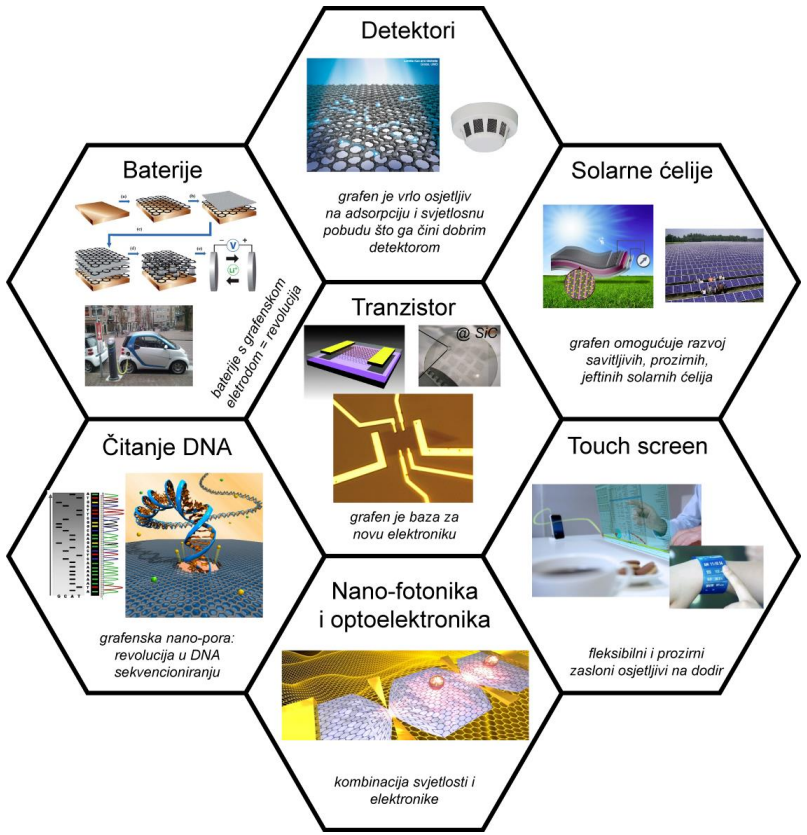
Intenzivna istraživanja počinju nakon kontrolirane izolacije individualnog sloja grafena 2004. godine



Revolucija dvodimenzionalnih materijala







Feature: Graphene

Drawing conclusions fro

The unique el
for the first tin

Geim and MacDonald, Physics Today 2007.

Dirac
rmions

≈ 10^6 m/s

The Nobel Prize in Physics 2010
Andre Geim, Konstantin Novoselov

The Nobel Prize in Physics 2010

Andre Geim

Konstantin Novoselov

Photo: Sergeom, Wikimedia Commons

Photo: University of Manchester, UK

Andre Geim **Konstantin Novoselov**

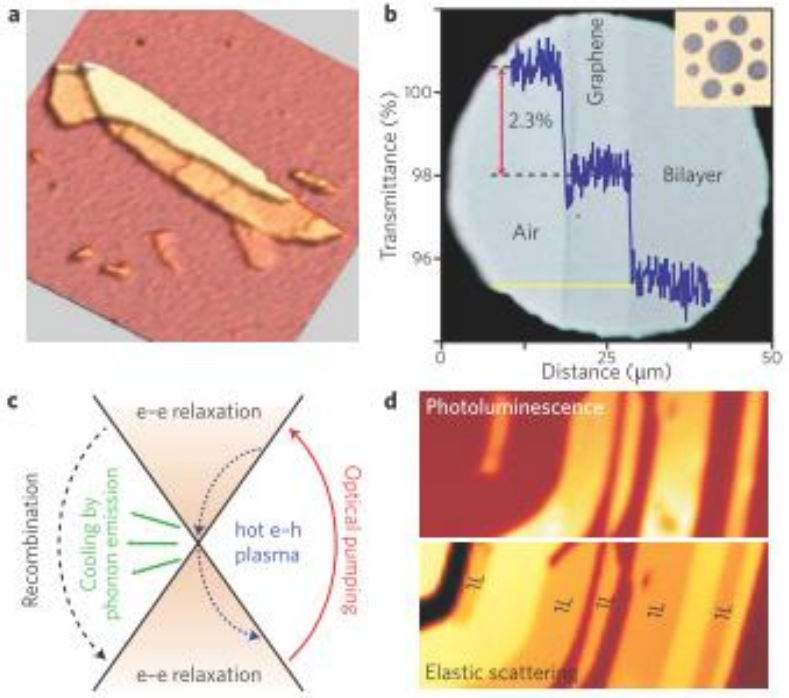
The Nobel Prize in Physics 2010 was awarded jointly to Andre Geim and Konstantin Novoselov *"for groundbreaking experiments regarding the two-dimensional material graphene"*

nature photonics
REVIEW ARTICLE
PUBLISHED ONLINE: 31 AUGUST 2010 | DOI: 10.1038/NPHOTON.2010.186

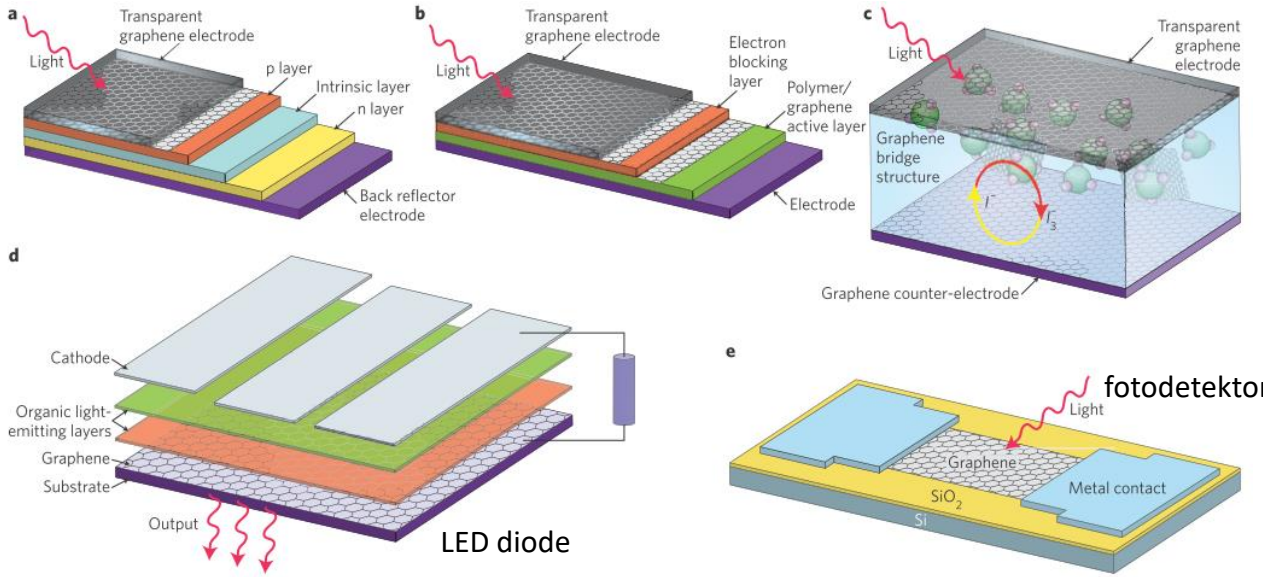
Graphene photonics and optoelectronics

F. Bonaccorso, Z. Sun, T. Hasan and A. C. Ferrari*

The richness of optical and electronic properties of graphene attracts enormous interest. Graphene has high mobility and optical transparency, in addition to flexibility, robustness and environmental stability. So far, the main focus has been on fundamental physics and electronic devices. However, we believe its true potential lies in photonics and optoelectronics, where the combination of its unique optical and electronic properties can be fully exploited, even in the absence of a bandgap, and the linear dispersion of the Dirac electrons enables ultrawideband tunability. The rise of graphene in photonics and optoelectronics is shown by several recent results, ranging from solar cells and light-emitting devices to touch screens, photodetectors and ultrafast lasers. Here we review the state-of-the-art in this emerging field.



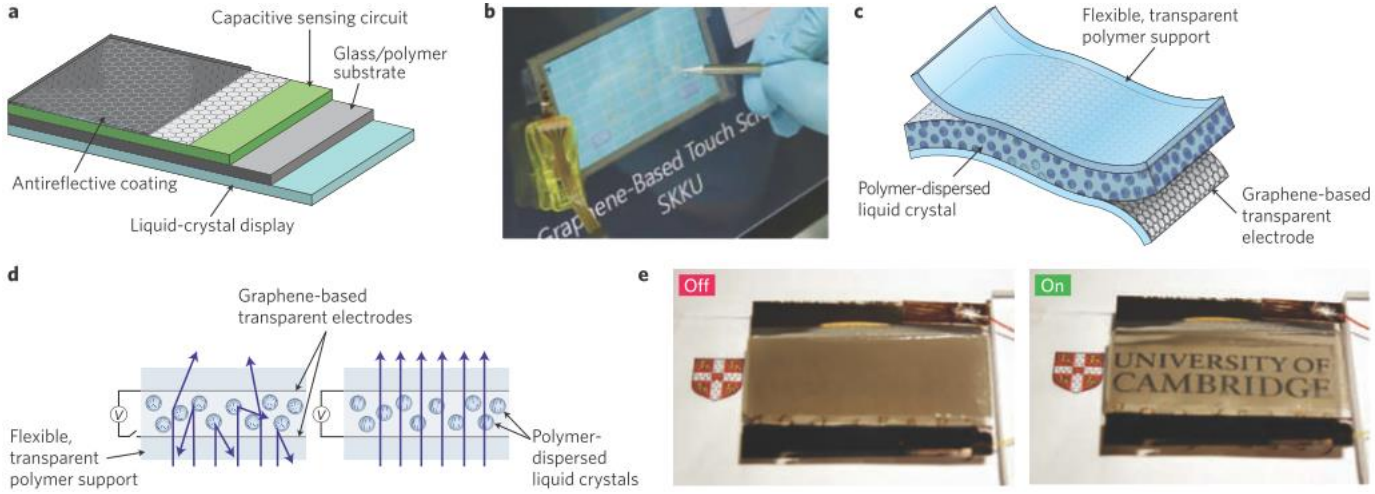
anorganske, organske i dye solarne ćelije



LED diode

fotodetektori

kapacitivni i rezistivni zasloni osjetljiv na dodir

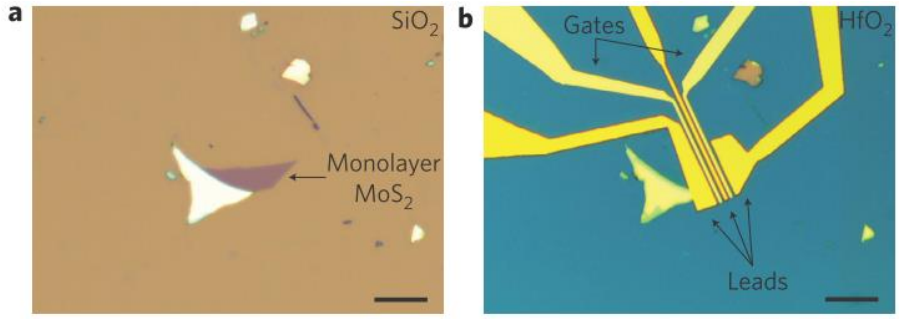


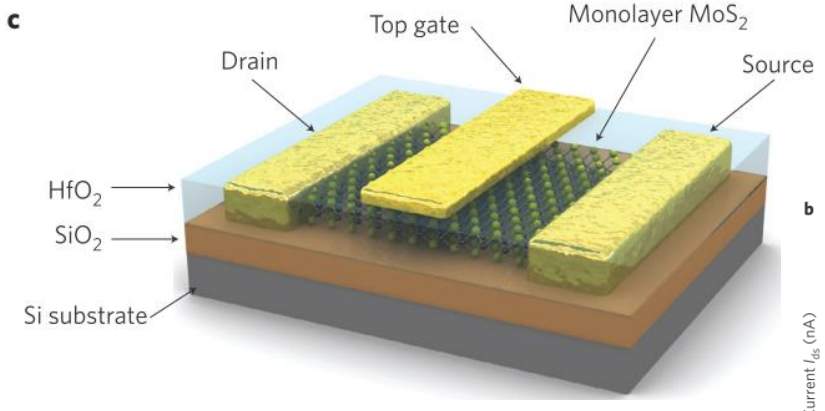
pametni prozori

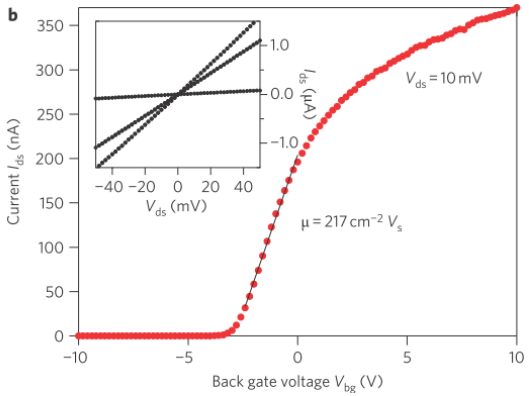
nature nanotechnology
PUBLISHED ONLINE: 30 JANUARY 2011

Single-layer MoS_2 transistors

B. Radisavljevic[1], A. Radenovic[2], J. Brivio[1], V. Giacometti[1] and A. Kis[1]*





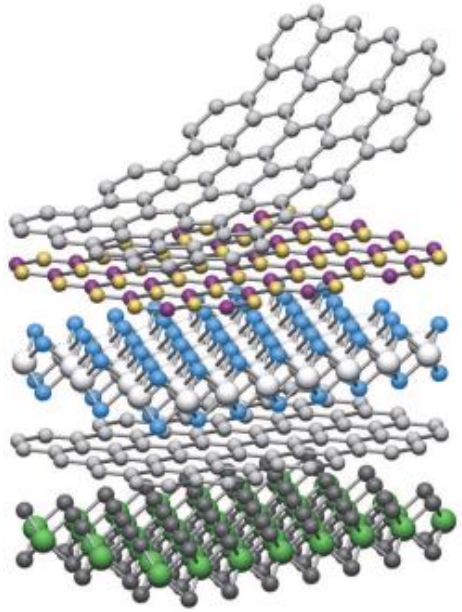


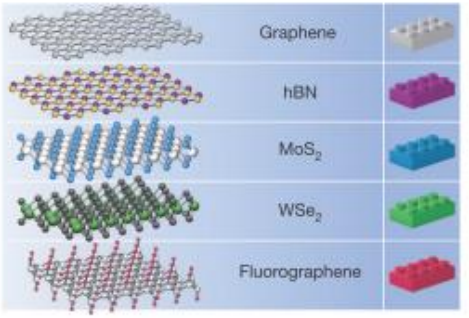
PERSPECTIVE RESEARCH

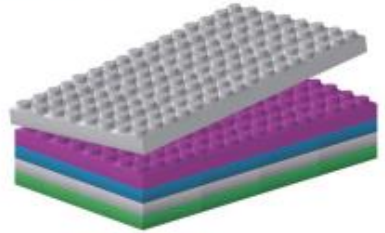
Van der Waals heterostructures

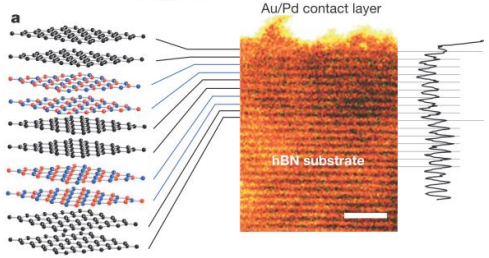
A. K. Geim[1,2] & I. V. Grigorieva[1]

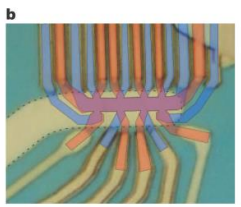
25 JULY 2013 | VOL 499 | NATURE | 419

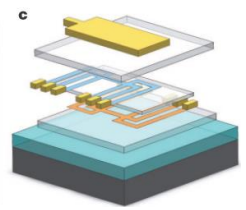




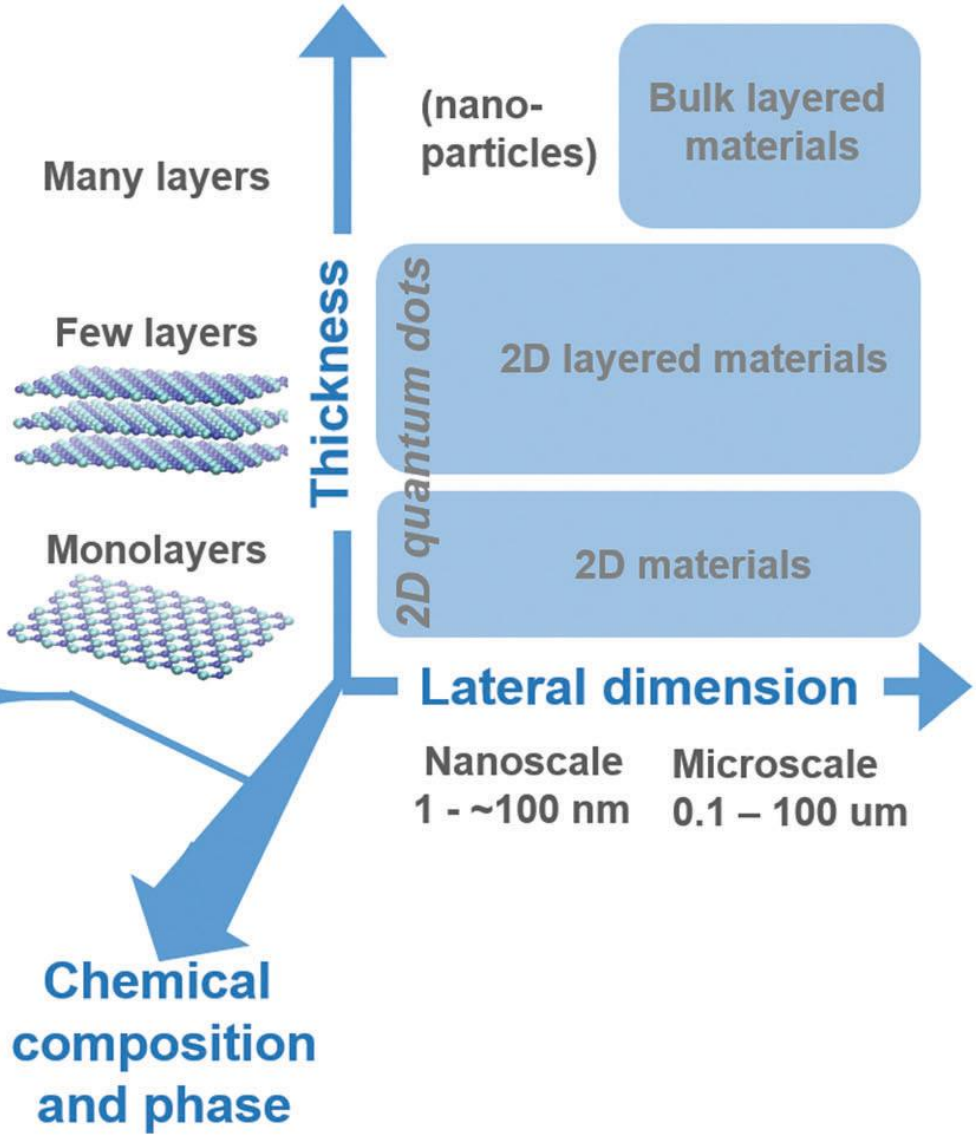








Mono-Chalcogenides	Trichalcogenides	Thiophosphates	Halides	Sulfates, Phosphates
$GeSe$, $GeTe$, $GaSe$, GaS, $InSe$, $AuSe$, Hf_2Se, Hf_2S, BiO_2Se, SnS, SiS, Ti_2S, $NiTe$, $CuTe$, $PbTe$, $SnTe$, $PtTe$, $HfTe$, FeS	Bi_2Se_3, Bi_2Te_3, Si_2Te_3, Sb_2Te_3, Bi_2S_3, In_2Se_3, In_2Te_3, As_2S_3, As_2Se_3, As_2Te_3, $NbSe_3$, Ga_2Se_3, TiS_3, ZrS_3, $ZrSe_3$, $ZrTe_3$, HfS_3, $HfSe_3$, $HfTe_3$, NbS_3, TaS_3, $TaSe_3$, $NpSe_3$, USe_3, US_3, B_2S_3, NpS_3, $ThTe_3$, UTe_3	$FePS_3$, $MnPS_3$, $NiPS_3$, $MgPS_3$, VPS_3, $CoPS_3$, $PdPS_3$, $ZnPS_3$, $CdPS_3$, $SnPS_3$, $CuPS_4$, $GePS_4$, $AlPS_4$, $ZnIn_2S_4$	$FeCl_3$, $FeCl_2$, $MgCl_2$, $CoCl_2$, VCl_2, $CrCl_3$, $MoCl_3$, $TiCl_2$, $AlCl_3$, $CdCl_2$, $FeBr_3$, $InBr_3$, $CrBr_3$, VBr_2, $CrBr_3$, $MoBr_3$, $TiBr_3$, $InBr$, PbI_2, VI_2, CdI_2, $TlCl$, $AuTe_2Cl$, $ZrCl$, $ZrCl_4$, UCl_5, WCl_6, $HfCl$, $SnCl_2$, $CuCl_2$, $HgCl_2$, $PbCl_2$, $AuBrCl_2$, $AuICl_2$, BCl_3, $TbCl_3$, $GaCl_3$, InI, TiI, AuI, HgI_2, $AuCl_2$, LaI_2, CeI_2, PTI_2, NdI_2, ZrI_2, ThI_2, BiI_3, TiI_3, InI_3, ThI_4, NbI_5, $TlBr$, $AuTe_2Br$, Sn_2SBr_2, TiF, $SnPO_3F$, $CuBr_2$, $HgBr_2$, $AuClBr_2$, $CdBr_2$, $AuBr_3$, $AlBr_3$, $PuBr_3$, UBr_4, $NpBr_4$, $HfBr_4$, $ZrBr_4$, SnF_4, PbF_4, NbF_4	$Pb_2O(SO_4)$, $(IO)_2SO_4)$, $Pb_3(PO_4)_2$
Dichalcogenides VSe_2, TiS_2, ZrS_2, SnS_2, HfS_2, ReS_2, PtS_2, NbS_2, TaS_2, MoS_2, WS_2, GeS_2, $TiSe_2$, $ZrSe_2$, $HfSe_2$, $ReSe_2$, $PtSe_2$, $SnSe_2$, $TaSe_2$, $MoSe_2$, WSe_2, $TcSe_2$, $TiTe_2$, $ZrTe_2$, VTe_2, $NbTe_2$, $TaTe_2$, $MoTe_2$, WTe_2, $CoTe_2$, $RhTe_2$, $IrTe_2$, $NiTe_2$, $PdTe_2$, $PtTe_2$, $SiTe_2$, $CuSbSe_2$, $CuSbS2$, $CuBiS_2$, PdS_2, $ReSSe$, Sb_2OS_2, TcS_2, SiS_2, $PdSeTe$, $PtSeTe$, $TaSeTe$, $CuAgTe_2$, $CuTe_2$	**Other chalcogens** $MnInSe_4$, Fe_3S_4, Y_2Te_5, Nd_2Te_5, La_2Te5, Ce_2Te_5, Pr_2Te_5, Sm_2Te_5, Cd_2Te_5, Tb_2Te_5, Dy_2Te_5, Ho_2Te_5, $Ge_3Bi_2Te_6$, $GeSb_4Te_7$	**Oxyhalides** $BiOCl$, $FeOCl$, $HoOCl$, $ErOCl$, $ErOCl$, $AlOCl$, $PbFCl$, $AlSeCl$, $InTeCl$, $Cd(OH)Cl$, $TmOCl$, $YbOCl$, $LnOCl$, WO_2Cl_2, WO_2I_2		**Layered Silicates** Egyptian Blue, Bentonite, Cariopilite, Greenalite, Garnierite, Nepourite, Berthierite, Amesite, Grovesite, Cronstedtite, Minnesotaite, Willemseite, Brucite derivatives, Dickite, Bayerite derivatives, Manadonite, Orthochlorite, Talc Chlorite, Clinochlore, Corundophilite, Sudoite, Cookeite
	Hydroxides $B(OH)_3$, $SnPO_3(OH)$, $B(OH)_3$, $Mo_2O_5(OH)$, $Cd(OH)Cl$	**Oxides** MoO_3, MnO_2, V_2O_5, PbO, SnO, Nb_2O_5		**Misc.** $MoSi_2$, $PtBi_2$, $GeAs_2$, $SiAs_2$, $NiPo_2$, TiB_2, ScB_2, MnB_2, AlB_2, HfB_2, P_2Sn_3, $Au_4In_3Sn_3$, $Th(NH)_2$, CrB, $SiAs$, $GeAs$
	Phosphides SiP, SnP, GeP, SiP_2, GeP_3, SnP_3, In_2AsP	**Nitrides** BN		
		Group IV Graphenes, Silicenes, Germananes		

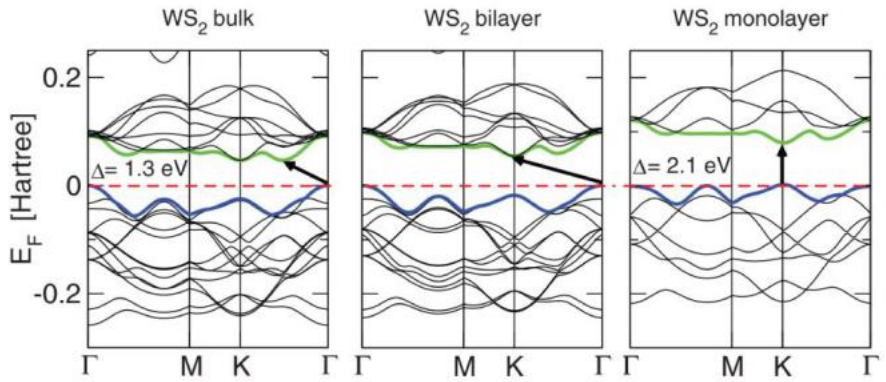


Wang et al. Chem. Soc. Rev. 2016, **45**, 1750-1780

nature nanotechnology
REVIEW ARTICLE
PUBLISHED ONLINE: 6 NOVEMBER 2012 | DOI: 10.1038/NNANO.2012.193

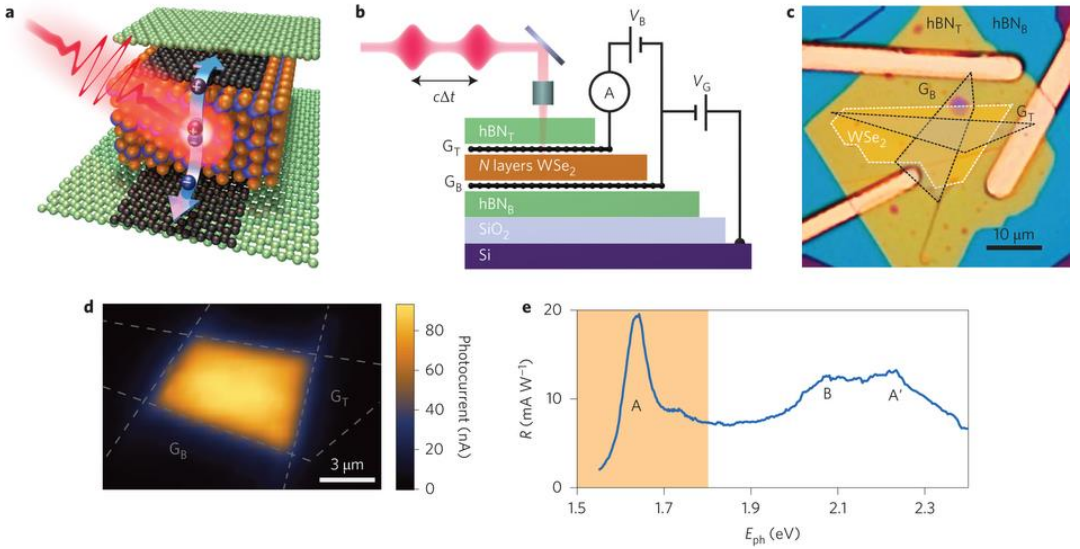
Electronics and optoelectronics of two-dimensional transition metal dichalcogenides

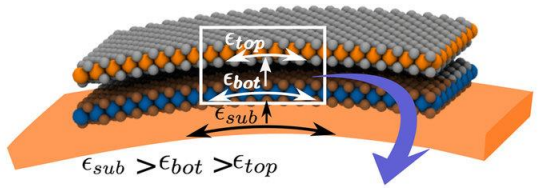
Qing Hua Wang[1], Kourosh Kalantar-Zadeh[2], Andras Kis[3], Jonathan N. Coleman[4,5] and Michael S. Strano[1]*

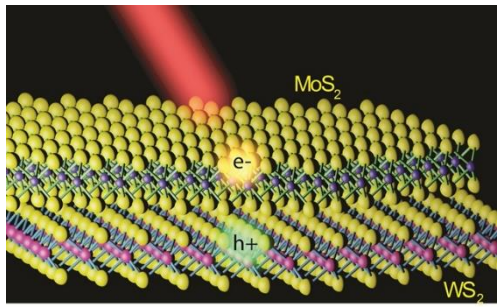


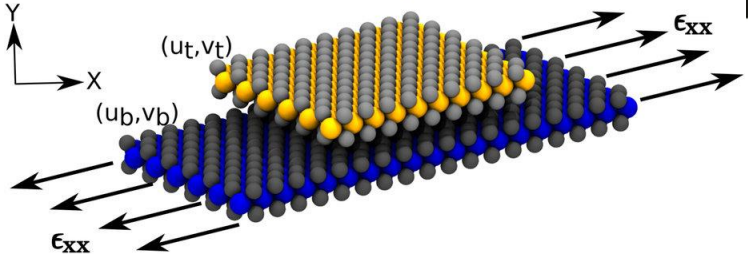
- Brzi fotodetektori i optički senzori
- Fotovoltaici
- LED
- Plazmonika / polaritonika
- Komunikacije
- Fleksibilna optoelektronika
- THz tehnologije

Nature Nanotechnology **11**, 42–46 (2016) | doi:10.1038/nnano.2015.227
Received 04 June 2015 | Accepted 01 September 2015 | Published online 05 October 2015

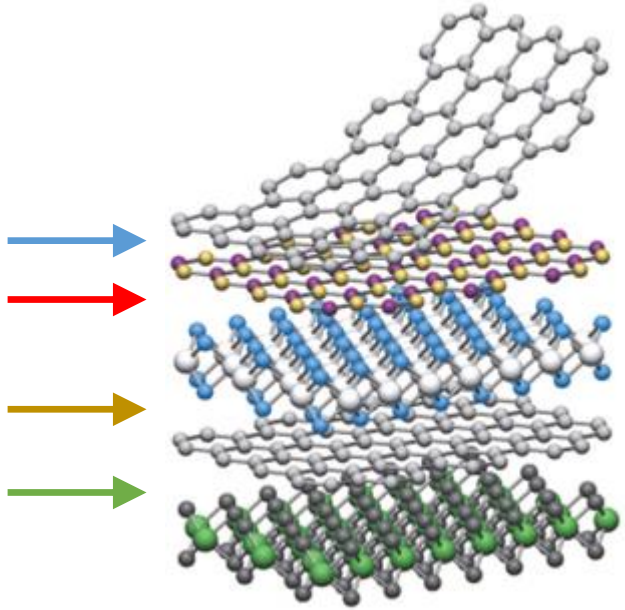


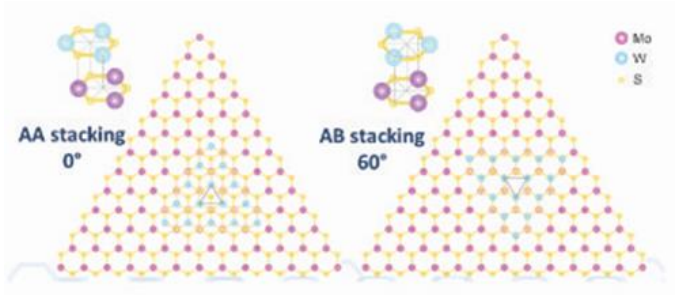






Scientific Reports **5**,
Article number: 21516 (2016)
doi:10.1038/srep21516

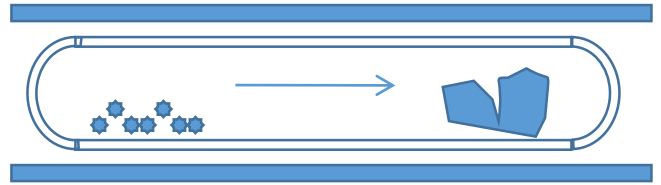




interlayer interaction
međudjelovanje slojeva

Svojstvo interfejsa, na primjer relativna kristalografska rotacija među slojevima, ključno je za raspored elektronskih vrpci i sami optički odgovor

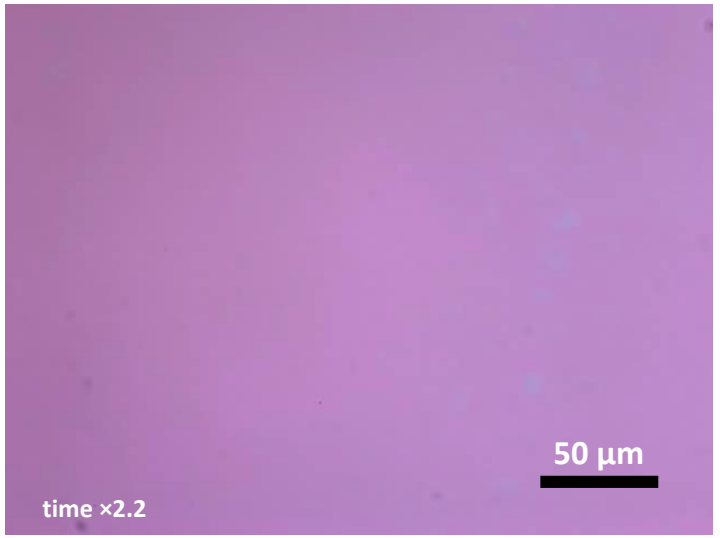
- Sinteza heterostruktura direktnim rastom (*in situ* optička kontrola) ili naknadnim mehaničkim transferom
- Naknadna fabrikacija uređaja baziranih na slojevima i heterostruktrama. Strukturna i elektronska karakterizacija
- Optički odgovor dobro definiranih heterostruktura: Raman, refleksivnost, fotoluminiscencija, … ekscitoni, trioni… , *pump-probe* i dinamika optičkih pobuđenja



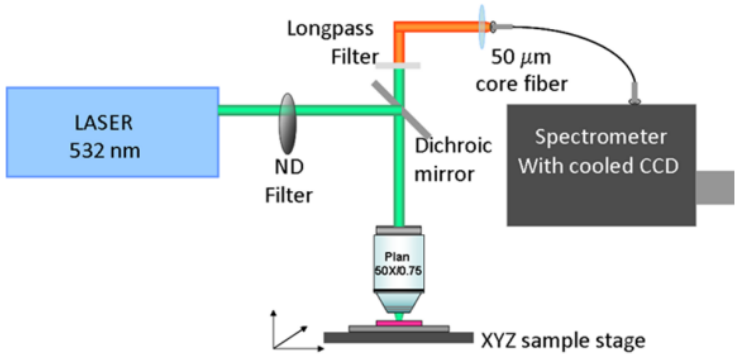
Chemical vapor transport

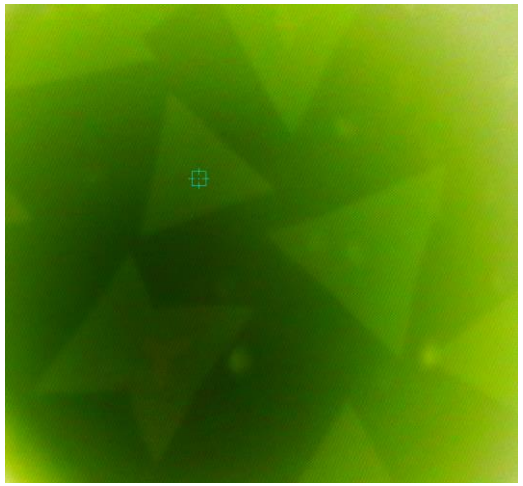
Chemical vapor deposition

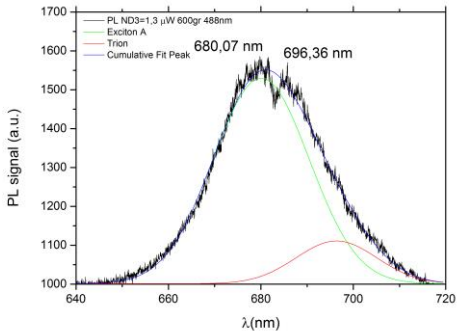
Predeposited larger MoO_3 amount + S slow

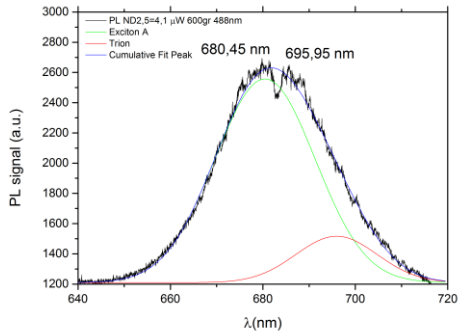


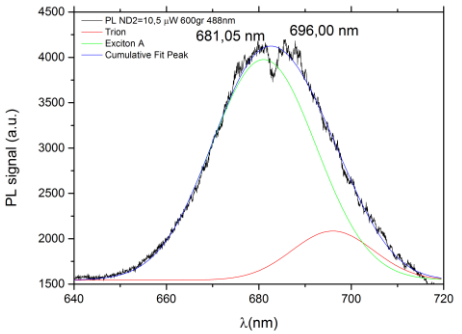
Karakterizacija optičkog odziva

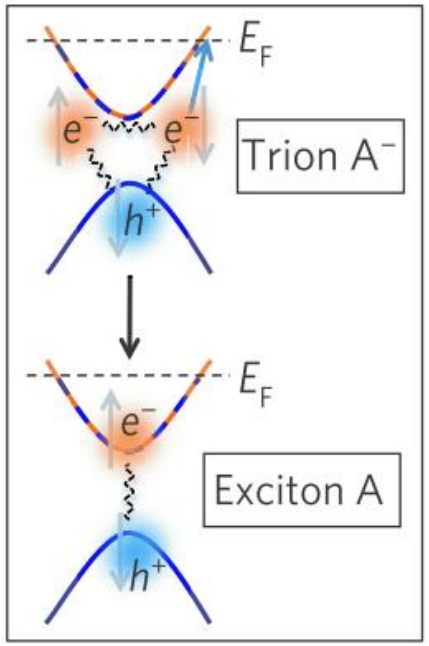


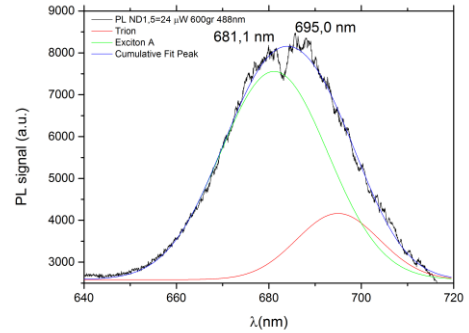


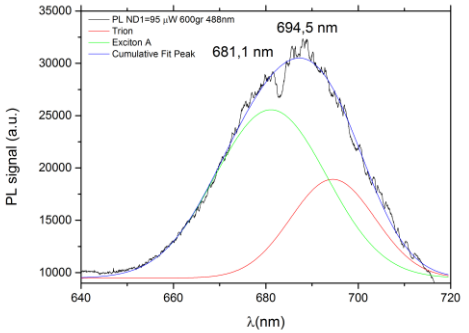












Mak et al., Nat. Mater. 2013.

Laser power	Trion position	Trion width	Exciton A position	Exciton A width
ND1=95 μW	1,79 eV	0,046 eV	1,82 eV	0,064 eV
ND1,5=24 μW	1,79 eV	0,045 eV	1,82 eV	0,063 eV
ND2=10,5 μW	1,78 eV	0,044 eV	1,82 eV	0,062 eV
ND2,5=4,1 μW	1,78 eV	0,043 eV	1,82 eV	0,061 eV
ND3=1,3 μW	1,78 eV	0,042 eV	1,82 eV	0,058 eV

Opis budžeta

	Troškovi po mjesecima u HRK				
	1-12	13-24	25-36	37-48	Total
1. Materijalni troškovi					
1.1. Optika i optomehanika za izgradnju konfokalnog mikroskopa zasnovan na *cage* sustavu (optička vlakna, sustav za prihvat zrake u optičko vlakno, sustav za prostorno čišćenje zrake, štapovi i stege za izgradnju cage sustava, optomehanički elementi kompatibilni s cage sustavom, 50/50 djeljitelj svjetlosti, izvor bijele svjetlosti s pripadnom elektronikom i napajanjem, zrcala, kinematički nosači za zrcala, štapovi, baze i vilice za učvršćivanje na optički stol) [vezano uz O8-A8.1]	100.000,00				**100.000,00**
1.2. Potrošni materijal (kemikalije za sintezu, kvarcne cijevi, podloge za rast uzoraka) [vezano uz O1, O2 i O6]	7.000,00	7.000,00	5.000,00	9.000,00	**28.000,00**
1.3. Raman filteri, dichroičko zrcalo za lasersku pobudu na 488 nm te pripadna optika za polarizacijskski osjetljiva mjerenja [vezano uz O8-A8.3 i O4]		28.500,00			**28.500,00**
1.4. Opto-mehaničke komponente (zrcala, kinematički nosači za zrcala, štapovi, baze i vilice za učvršćivanje na optički stol) [vezano uz O8]				5.200,00	
1.5. AFM probe [vezano uz O5-A5.3]				15.000,00	**15.000,00**
Ukupno 1	**107.000,00**	**35.500,00**	**5.000,00**	**29.200,00**	**171.500,00**
2. Troškovi osoblja					
A. Plaće					
2a.1. Bruto plaća poslijedoktoranda/poslijedoktorandice [vezano uz O6-A6.1 i A6.2, i O11]				155.000,00	**155.000,00**
Ukupno A	**0,00**	**0,00**	**0,00**	**155.000,00**	**155.000,00**
2b.1. Školarina za tri godine poslijediplomskog studija za novozaposlenog PhD studenta/studentice [poglavito vezano uz O9]	8.000,00	8.000,00	8.000,00		**24.000,00**
Ukupno B	**8.000,00**	**8.000,00**	**8.000,00**	**0,00**	**24.000,00**
C. Usavršavanje voditelja projekta i suradnika					
2c.1.					**0,00**
Ukupno C	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Ukupno 2	**8.000,00**	**8.000,00**	**8.000,00**	**155.000,00**	**179.000,00**

3. OPREMA					
A. Nova oprema					
3a.1. Spektrograf s trostrukim nosačem optičkih rešetki (300 l/mm; 600 l/mm and 1800 l/mm) grating spectrograph [vezano uz O8-A8.3, te O9, O10 i O4]		76.000,00			**76.000,00**
3a.2. Detektor baziran na pojačanju elektrona u nabojno vezanim detektorima (eng. *electron multiplying charge copuled device-EM CCD*) i pripadni softverom za prikupljanje podataka [vezano uz O8-A8.4, te O9, O10 i O4]			226.800,00		**226.800,00**
3a.3. Jednomodni Raman laser @ 488 nm [vezano uz O8-A8.3 i O4]		66.750,00			**66.750,00**
Ukupno A	**0,00**	**142.750,00**	**226.800,00**	**0,00**	**369.550,00**
B. Servisno održavanje opreme					
3b.1. Servis femtosekundnog laserskog sistema [vezano uz O10-A10.1]		19.000,00			**19.000,00**
Ukupno B	**0,00**	**19.000,00**	**0,00**	**0,00**	**19.000,00**
C. Nadogradnja opreme					
3c.1. Nadogradnja AFM uređaja (precizno pozicioniranje uzorka s ručnim xy mikrometarskim translatorom i pripadni nosači) [vezano uz O5]	17.500,00				**17.500,00**
3c.2. motorizirani xy translator s DC servo kontrolerima i pripadni nosač uzoraka [vezano uz O8-A8.1 i O4]	98.000,00				**98.000,00**
Ukupno C	**115.500,00**	**0,00**	**0,00**	**0,00**	**115.500,00**
Ukupno 3	**115.500,00**	**161.750,00**	**226.800,00**	**0,00**	**504.050,00**
4. Diseminacija i suradnja (do 70.000,00 HRK godišnje)					
4.1. Diseminacija rezultata na međunarodnim konferencijama (6 konferencija); 10.000,00 kn po konferenciji (4.000,00 HRK kotizacija + 4.000,00 HRK troškovi putovanja + 4x500 HRK dnevnica) [vezano uz O1, O4, O5, O7, O9 i O10]	10.000,00	10.000,00	10.000,00	30.000,00	**60.000,00**
4.2. Putni troškovi za 2 osobe za odlazak na µARPES mjerenja na sinhrotronu [vezano uz O7-A7.3]				20.000,00	**20.000,00**
4.3. Troškovi publiciranja [vezano uz O1, O9, O10]		15.000,00		7.500,00	**22.500,00**
Ukupno 4	**10.000,00**	**25.000,00**	**10.000,00**	**57.500,00**	**102.500,00**
5. Posredni troškovi (najviše do 5% ukupno traženih sredstava) **samo uz detaljno obrazloženje načina korištenja*					
5.1.					**0,00**
Ukupno 5	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
TOTAL (1+2+3+4+5)	**240.500,00**	**230.250,00**	**249.800,00**	**241.700,00**	**957.050,00**




Hvala na pažnji !

Iva Šrut Rakić
Davor Čapeta
Borna Pielić
Nataša Vujičić
PhD student
Postdoc
Marko Kralj

HrZZ
Hrvatska zaklada za znanost